



## A Seismic Factor of Radon Danger on a Case Study of Armenia

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### Abstract

For the first time, on the basis of Spitak earthquake experience (Armenia, December 1988), it was found that an earthquake causes intensive and prolonged radon releases that are quickly dispersed in the open air and that is why they are not usually registered but contrastingly displayed in covered premises (such as dwelling houses, schools, kindergartens) even if they are at a considerable distance from the epicenter of the earthquake. The duration of the release includes the period starting from the first foreshock and ending with the last aftershock, i.e. several months.

The radiation intensity and duration of the influence are in direct correlation with the intensity of the earthquake. The area affected by radiation is larger than the territory of Armenia. The scale of this impact on the effected population is twelve times higher than the number of people injured in the Spitak earthquake.

Data collation from the 2000–2005 time period indicates that a contrasting increase in indoor radon concentrations in Yerevan (several times excessive vs. the sanitary norm) is predetermined not only by strong earthquakes ( $M \geq 4.5$ ), but also by the weak ( $M < 4.5$ ), small-depth (H-5-15km), regional ( $R \leq 200$  km from Yerevan) earthquakes and earthquake swarms occurring in the territory of Armenia, as well as in Iran and Turkey.

**Keywords:** Armenia, Radon danger, Seismic activity, Earthquakes, Cancer.

### 1. Introduction

The reality of the radon problem is universally recognized today. In accordance with data provided by IAEA, natural sources of radiation are responsible for the main contribution (up to 70%) of the total radiation dose. The main contributions are materials with increased content of natural radionuclides and radon accumulating in buildings. About 44% of the total radiation dose arises from radon ( $^{222}\text{Rn}$ ,  $\alpha$ -decay,  $t_{1/2} = 3.82$  days) and its short-lived decay products  $^{218}\text{Po}$  ( $\alpha$ -decay,  $t_{1/2} = 3.2$  minutes),  $^{214}\text{Pb}$  ( $\beta$ ,  $\gamma$ -decay,  $t_{1/2} = 27$  minutes),  $^{214}\text{Bi}$  ( $\beta$ ,  $\gamma$ -decay,  $t_{1/2} = 19$  minutes) and  $^{214}\text{Po}$  ( $\alpha$ -decay,  $t_{1/2} = 3.82$  days).

Mortality attributable to this is about 80000 people per year. Relatively recent reports indicate a correlation of the incidence of lung and larynx cancers (it is a known fact that radon is the second factor, after tobacco smoking, responsible for these illnesses), myeloid leukaemia, melanoma, cancer of the kidney and certain childhood cancers to average radon exposure in dwellings. That is why this problem was included in the national and governmental programs in many countries e.g. United States of America, Sweden, and United Kingdom [1].

The recognized concept of radon safety and NORM, TENORM and other standards developed on its basis are underpinned by constantly acting factors during stable state of the earth's crust. The world views the ecological safety of earthquakes from a position of catastrophic destruction and human casualties and the radioactive safety of the population is viewed as a nuclear technology catastrophe [2,3]. However, they do not pay attention to radon danger in seismically active regions with unstable state of the earth's crust.

There is no information in literature about the influence of earthquake epicenter and the radius of its effects on radon concentration in dwellings. There are no data concerning the radiological implications of dust during destruction caused by earthquakes.

The presence of high radon concentrations in seismically active regions is a different issue. Here radon concentrations are influenced by earthquake areas and active tectonic fault zones. In addition to the natural radioactivity of the rock, a major role is played by the physical – mechanical properties of the rock, textural – structural peculiarities that stipulate the percentage of rock porosity and radiometric parameters such as the 'estimated coefficient'. Moreover, soils behave not in an isolated way but as a constituent of the engineering-geological peculiarities of the site, with all the ensuing consequences. The extended occurrence of the radon emanation field is rather a significant factor; opinions concerning its formation differ. As a matter of fact, a significant increase in radon concentration is a function of the earthquake.

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The problem of populated areas in the general sphere of problems connected with earthquakes is usually considered only in one aspect, namely, that of seismically stable building and structures. But, as the results of our mainly ecological investigations have shown, catastrophic destruction caused by earthquakes, with all ensuing consequences, is only the tip of the iceberg. It is possible to aspire for prediction of earthquakes, to have seismically stable houses, and to avoid direct fatalities, but it is impossible to avoid the danger of death, when there is no knowledge of such a danger - this danger is radiation [4-8].

For the first time, interrelation of the indoor radon concentration level and occurrence of the earthquakes in Armenia was proved by the research team of the SEUA and CENS NAS RA (supervised by Prof. E. A. Saghatelyan). At the example of Spitak earthquake (Armenia, December, 1988) a new approach to the earthquake was identified — causing not only catastrophic destruction but also extended radon radiation as a factor that affects the health of the population. The latter exceeds the manifold destruction-conditioned consequences both territorially and numerically.

The interval of radon action is from the first foreshock to the last aftershock, i.e. several months. The area, which was affected by radiation, is larger than the territory of Armenia. The scale of this impact on the affected population is twelve times higher than the number of people injured in Spitak, Gyumri (Leninakan) and other settlements (toll of injured – 25,000 people, compared to the projected diseases caused by high levels of radiation in non-adapted population – over 300,000). The basis for this conclusion is the set of data on indoor radon monitoring in Yerevan City.

The fact that the earthquakes in Armenia are often weak, small-depth and occur in swarms [9, 10] served an impetus for subsequent investigations, which were started from 2005.

## 2. Subject and Methodology of measurements

The research is underpinned by the results of indoor radon monitoring conducted in Yerevan (Armenia) and its surroundings from 1987 to 1993 and also from 2005 to 2007 (during stable and unstable situation of the Earth's crust). The area is characterized by low activity volcanogenic sedimentary rocks. Armenia is a highland region, characterized by young volcanism. The volcanic regions have not yet cooled and the region is seismically active. These active geotectonic processes and the increasing industrialization make public safety an issue with regard to natural and industrial catastrophes. Measurements were made from 1987–1993 using a radon meter (model FAS-P-2 model supplied with a filter type AFA-PSP-20, manufactured

in Russia). The instrument assures a 95% efficiency of radon aerosols gathering and a measurement error of about 40%.

Air samples were taken in basements and measured in underground, single- and multi-storied buildings throughout the study period. While carrying out investigations, recommendations were made on the methodology for measuring the volume activity of radon and its daughter products in the air of dwellings and other buildings in Armenia.

The total number of samples taken and analyzed for 1987-1993 time period was 5228. Mean monthly values of measurements were generated, irrespective of the type of building, through a moving average formula and graphs were constructed from the data obtained.

Indoor radon measurements for the 2005-2007 time period were done in Yerevan in an unventilated room located in the basement of the Center for Ecological-Noosphere Studies NAS RA. Daily measurements were done on a RAD-7 electronic radon detector (DurrIDGE Co, USA) which assures accurate data (5% accuracy in any humidity). Of the three possible modes we selected Auto-mode. This allowed obtaining more precise averaged data. For the 2005–2007 time period 1442 measurements of indoor radon concentration were carried out.

The earthquake data were collected using the earthquake catalogues from the websites which are as follows:

- National Survey for Seismic Protection of Republic of Armenia (NSSP RA).
- Kandilli Observatory and Earthquake Research Institute (KOERI) and National Earthquake Monitoring Center (NEMC) of Bogazici University of Turkey.
- Iranian Seismological Center of Institute of Geophysics (IRSC), University of Tehran.

The studies were carried out with regard to all the earthquakes with no magnitude limitations. It should be noted that there exist a number of supposed faults in the north of our measurement polygon [10].

Based on the obtained data and using GIS software we produced maps and constructed graphs, which indicate:

- Spatial and temporal dynamics of the earthquake epicenters (Fig. 9),
- Magnitude-temporal dynamics of earthquakes (Fig. 10),
- Daily dynamics of variations of indoor radon concentrations (Fig. 10).

In all, 6670 measurements were carried out.

### 3. Results and discussion

#### 3-1 Spitak earthquake example

Statistical processing of the radon monitoring data 1987-1991 (Fig.1) superimposed on the dynamics of the earthquake clearly showed that, irrespective of seasonal oscillations, the radon concentration in the dwellings was within normal levels during 1987. A growth in the radon concentration occurred from the beginning of 1988 and in July and August it exceeded the concentration during the previous year by eight and ten times. In January 1989, the mean radon concentration had increased by nearly fourteen times. As follows from Fig.1, three spikes are evident, characterizing intensive releases of radon. These correspond, with some delay in time, to the first foreshock, the main shock, and the late aftershocks. The time interval between the first foreshock and the last aftershock, characterized by multiple increases in radon concentration in closed buildings, could be clearly seen.

It is interesting to note that the radon concentration peaks in the houses of Yerevan were generally a mirror image (delayed in time) of the graph of subsoil radon monitoring registered at Gyumri regime station (Fig. 2); they differ only in the change of concentration levels. In using the soil radon method, the investigator can determine by intersection only short-term anomalies, which are characterized by an increase or decrease (only 20%) of concentrations of the original background [11]. As for the indoor radon monitoring, the question is not only about the repeated increase of the concentration long before the earthquake, but also about the possibility of correlating the whole pattern of variations in indoor radon with the instabilities in the earth's crust.

The annual average indoor radon concentrations in Yerevan in 1987, 1988, 1989, 1991 and the indices of the variations are shown in Table 1. They show clear differences between stable periods (1987, 1991) and unstable periods (1988, 1989) of the Earth's crust.

At the same time, as may be seen from Figures 1 and 2, the radon concentration curve coincides with the positive spike at Jermuk seismic station. These results demonstrate the release of radon into the atmosphere at the epicenter and its intensive accumulation in the subsoil layer even at a considerable distance from the epicenter. It is important to note that actually there is no vivid central spike and according to the results of daily measurements, this whole interval before and after the earthquake is characterized by dozens of spikes (Fig. 3).

Fig.4 shows the effective dose calculated at monthly intervals and projected to an annual figure. Here also, curves characteristic of the stable state and for the state during the earthquake are distinctly seen. In January 1989, the projected annual dose from radon

and its daughters was about 16 mSv. If the 1987, 1991, 1992, and 1993 data, showing doses from 0.183 to 0.435mSv (less than twice the global average) are taken as typical, then the dose in January 1989 was fifty times more than that in the 'stable' periods and sixteen times more than the global average.

Near the epicenter of the earthquake (Nalband, Spitak and alongside the whole disaster zone), the indoor radon concentrations and hence the effective dose from radon were many times higher.

The effect of radon is different in diverse environments. A contrasting increase in indoor radon concentration became a carcinogenic risk factor the consequences of which have continued to the present. In accordance with the annual statistical reports of the Ministry of Health of the Republic of Armenia, the first flash of cancer diseases was recorded in 1989-1990 while the second (the most intensive tumor diseases) was recorded fifteen years later from 2002 up to the present (Fig.5).

Radon flashes in near-earth atmosphere intensively ionized the air with the formation of air ions which provoked total respiratory diseases with a peak falling from 1988-1990 (Fig.6).

The increase in radon in water sources induced digestive diseases with a peak also falling from 1989-1990 (Fig.7).

In the upper lithosphere layers the increase in alpha-radiation increased the level of neutron radiation of the Earth with the infrasound, which induced mental diseases (Fig.8).

This phenomenon was established also during the Noemberian earthquake of 1997, entailing no human loss or ravages. The radiation intensity and duration of the influence are in direct correlation with the intensity of the earthquake.

Table 1. Indoor radon concentrations in Yerevan

Year	Mean concentration Bq/m <sup>3</sup>	Dispersion $\alpha^2$	Root mean square dispersion, d	variation coefficient V%
1987	9.25	0.0106	0.0103	41.32
1988	41.66	0.864	0.924	82.5
1989	110.15	4.444	2.109	70.81
1991	6.29	0.004	0.069	37.05

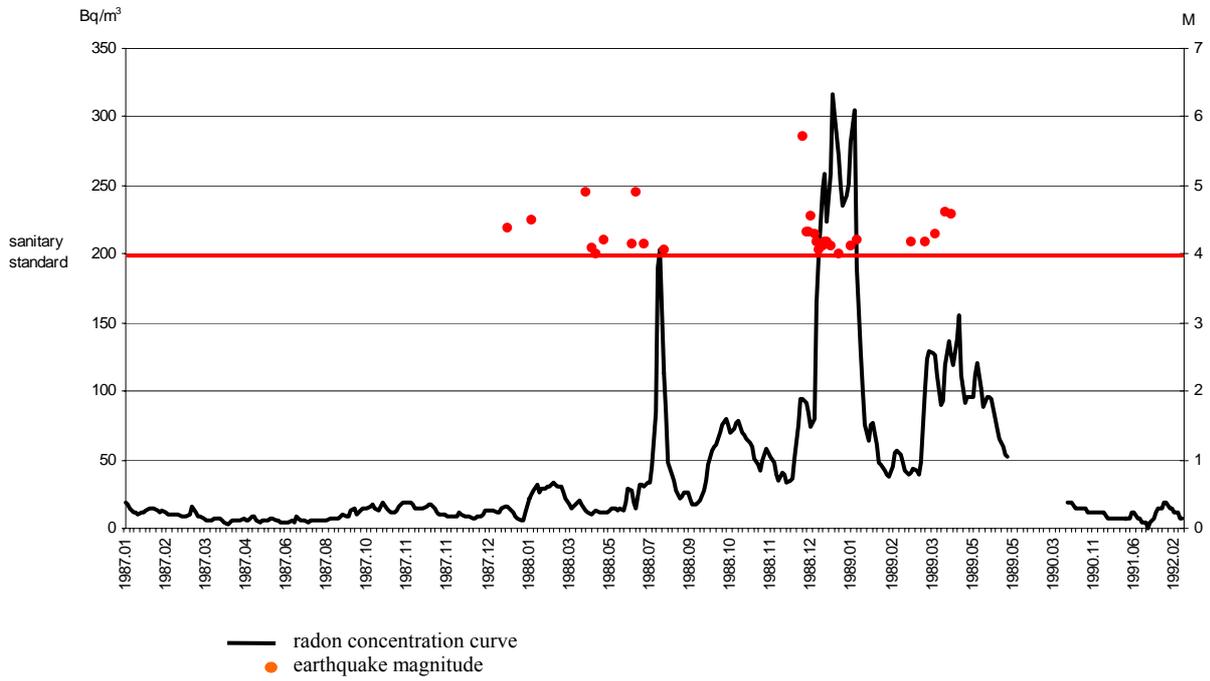


Fig. 1. The dynamics of changes in indoor radon concentrations in Yerevan and the earthquake magnitudes (points) from 1987-1993

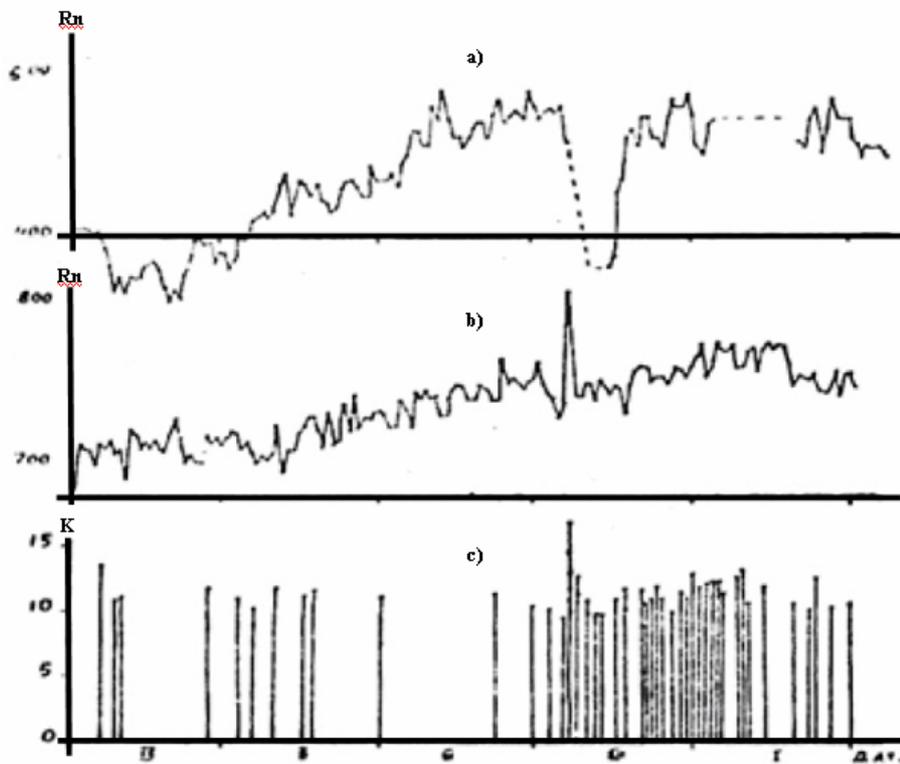


Fig. 2. Spitak earthquake operational precursors: (a)Gyumri seismic station; (b)Jermuk seismic station; (c)seismic activity in the region (the graph of subsoil radon monitoring, registered at Gyumri regime station by V.P.Rudakov and Basnetsian, 1989)

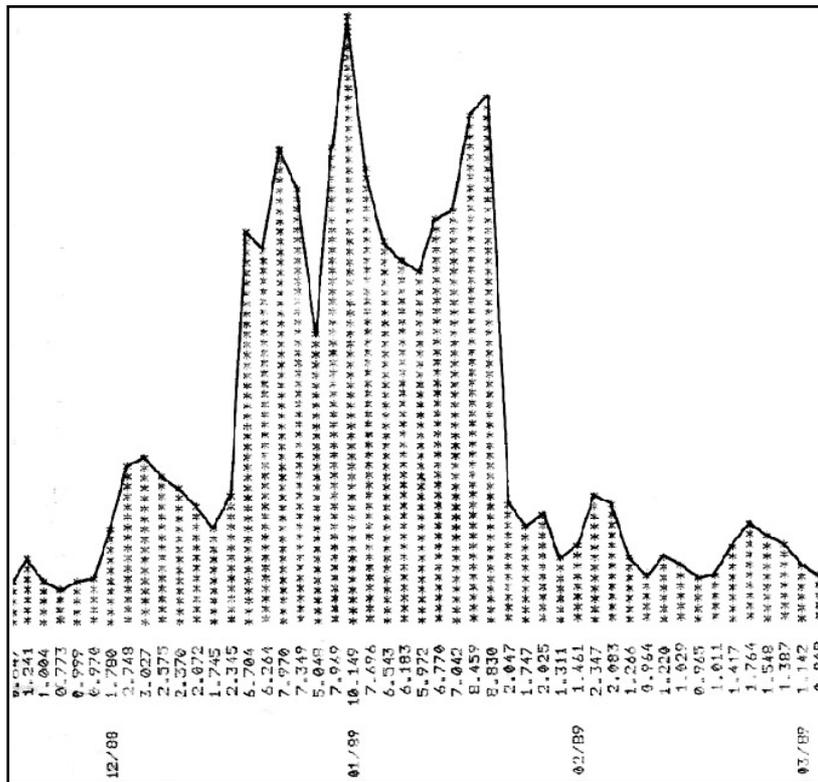


Fig. 3. Extract from the graph of daily radon concentration (pCi/L) measurements

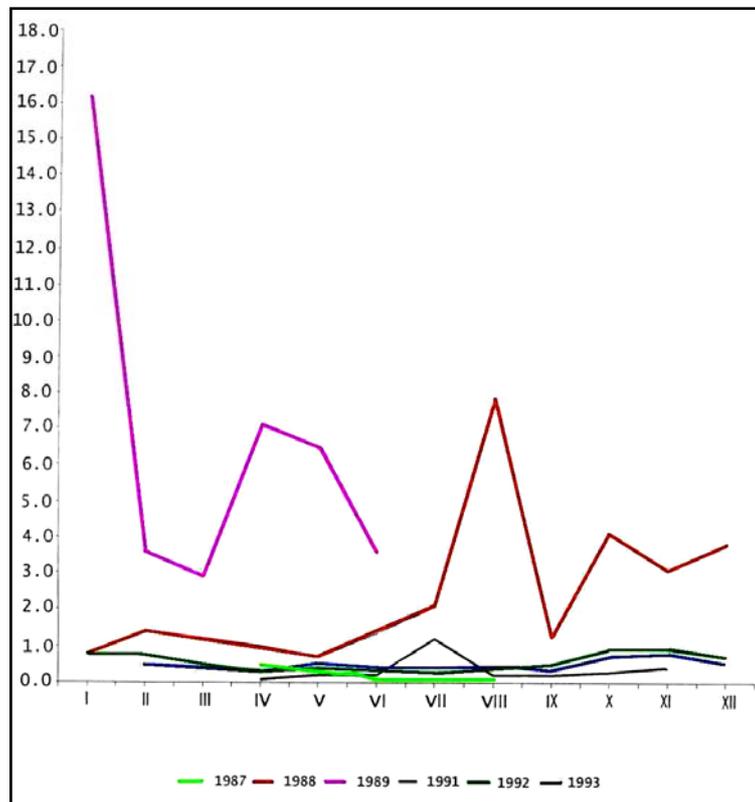


Fig. 4. Annualized effective doses from exposure to radon in Yerevan

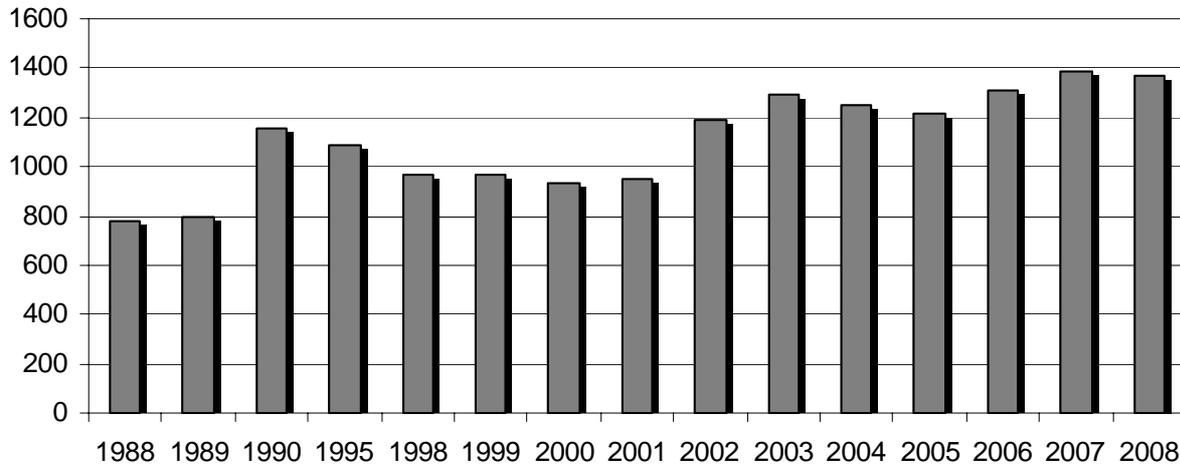


Fig. 5. Malignant cancer diseases of adults and teenagers (Per 10,000 adults and teenagers) In accordance with annual statistical reports of Ministry of Health of RA

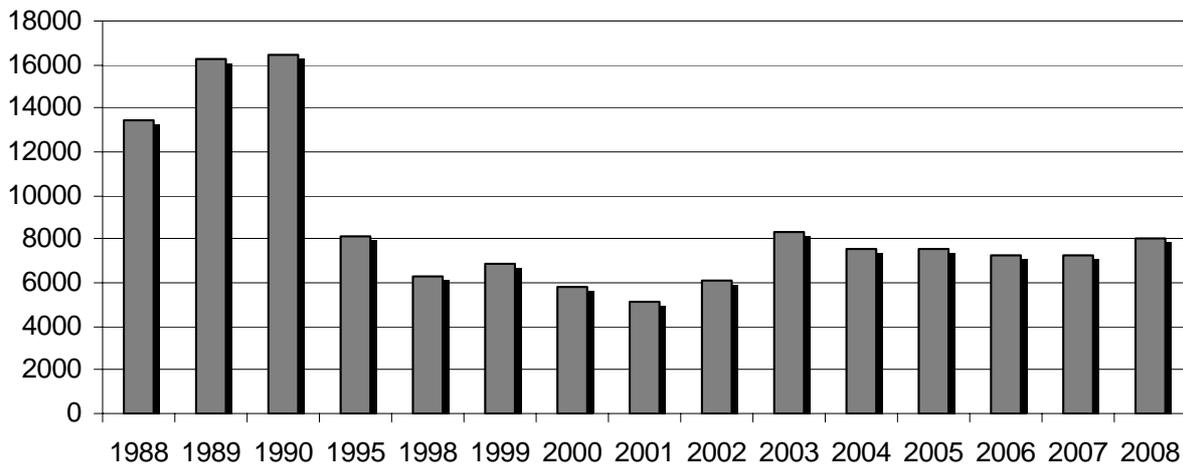


Fig. 6. Respiratory diseases in adults and teenagers (per 10,000 adults and teenagers) In accordance with annual statistical reports of Ministry of Health of RA

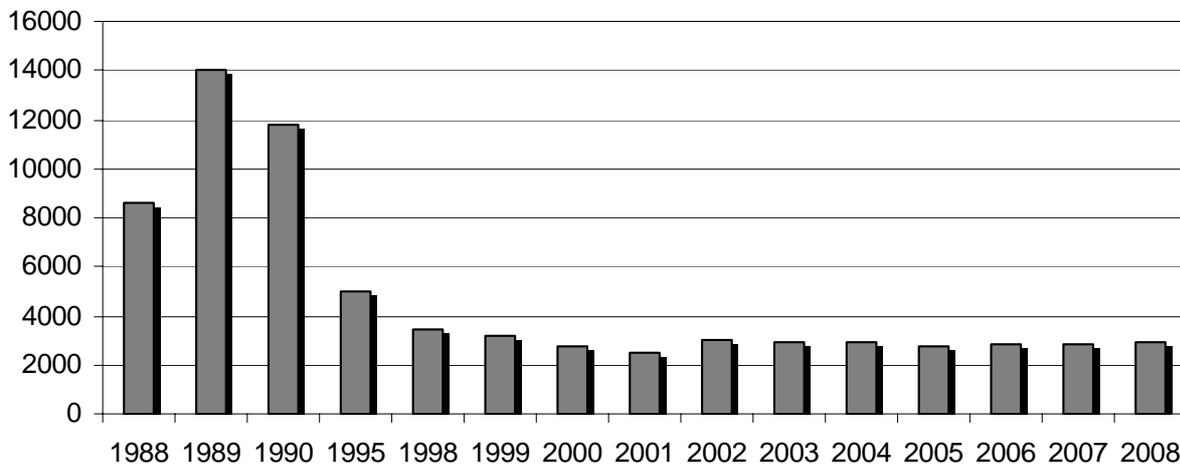


Fig. 7. Digestive system diseases of adults and teenagers (per 100,000 adults and teenagers) In accordance with annual statistical reports of Ministry of Health of RA

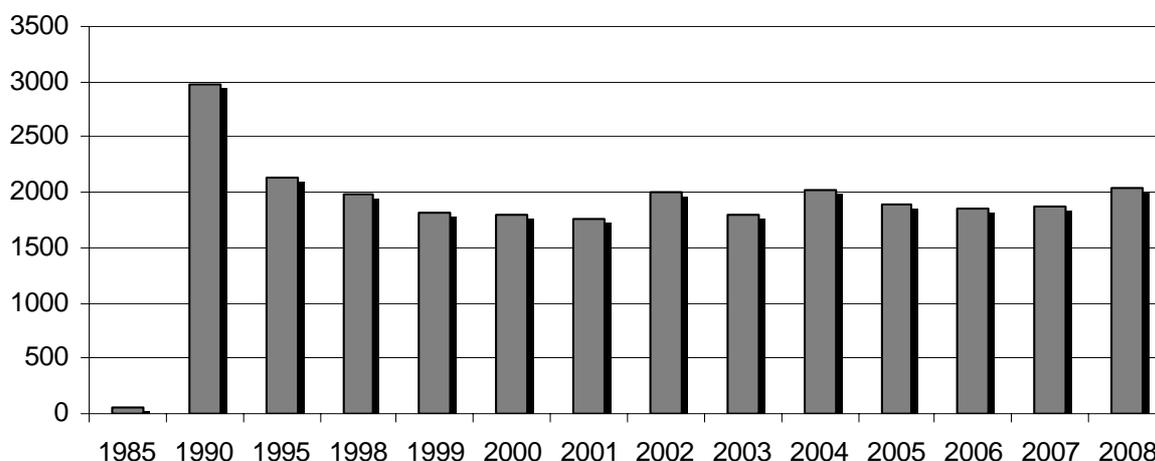


Fig. 8. Mental diseases of adults and teenagers (Per 10,000 adults and teenagers) In accordance with annual statistical reports of Ministry of Health of RA

### 3-2 Weak earthquakes for the 2005-2007 time period

As seen from Fig. 9 in January 2005, the concentration was not excessive vs. the accepted standard and it started increasing from February to the end of April showing a several time excess vs. the standard (600-700Bq/ m<sup>3</sup>).

The analysis of seismic data for the same period evidenced a whole series of weak earthquakes. Then, up to July no earthquakes were recorded. In July, two earthquakes occurred and up to October 2005 no earthquakes were recorded. Beginning from October, a contrasting increase in indoor radon concentration was registered, some tenfold excessive vs. the standard. This can be explained not only by seasonal variations, but also by earthquakes which occurred between October and December 2005.

In 2006 and 2007, too, the changes in indoor radon concentration levels clearly coincided with the recorded weak earthquakes, the parameters of which are given in Table 2. Thus, the indoor radon monitoring data from 2005 to 2007 indicates that weak and medium magnitude earthquakes indoor radon concentrations show 3 to 8 time increases which remain unchangeable for several days only [10, 11]. In all, for the studied period, about 70 earthquakes correlated with the increased indoor radon concentrations.

In Figure 10, the spatial distribution of earthquake epicenters which occurred from 2005–2007 has been shown. Epicenters of earthquakes, which are correlated with increased indoor radon concentrations, are marked as red points.

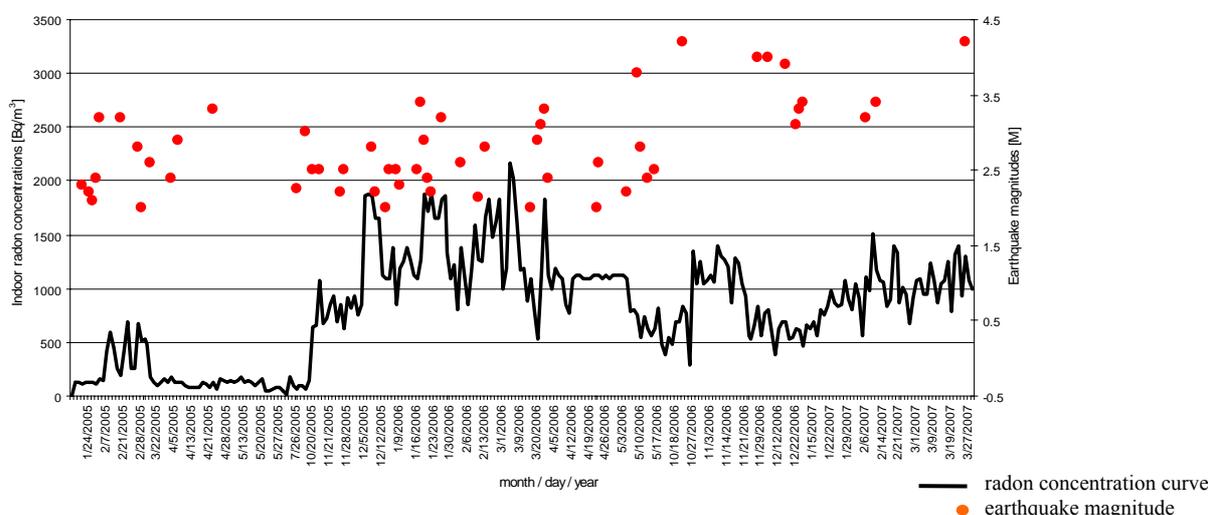


Fig. 9. The dynamics of changes in indoor radon concentrations (measured in the basement of Ecocenter) in Yerevan and the earthquake magnitudes occurring in Armenia and adjacent regions from 2005.01 to 2007.04

Table 2. Main parameters of earthquakes, which are correlated to the increased indoor radon concentrations

1	20.01.2005	2.3	6	40.08	44.25	22	31.10.2005	2.5	8	39.73	43.8	43	28.03.2006	3.1	9	41.75	45.25
2	27.01.2005	2.2	10	41.22	43.7	23	24.11.2005	2.2	12	41.02	43.52	44	01.04.2006	2.4	8	41.13	43.73
3	28.01.2005	2.1	10	39.58	44.32	24	25.11.2005	2.5	15	39.75	43.65	45	22.04.2006	2	5	41.37	44.27
4	31.01.2005	2.4	12	39.63	44.33	25	07.12.2005	2.8	15	41.5	43.02	46	24.04.2006	2.6	7	39.38	44.85
5	02.02.2005	3.2	7	39.32	44.52	26	08.12.2005	2.2	9	40.65	43.73	47	05.05.2006	2.2	5	41.3	44
6	14.02.2005	3.2	13	39.5	44.02	27	13.12.2005	2	13	41.3	44.13	48	09.05.2006	3.8	15	39.32	44.23
7	25.02.2005	2.8	13	41	43.97	28	27.12.2005	2.5	10	40.93	43.23	49	10.05.2006	2.8	10	41.63	44.2
8	28.02.2005	2	15	41.05	43.97	29	08.01.2006	2.3	10	41.05	44.37	50	13.05.2006	2.4	5	39.83	43.97
9	12.03.2005	2.6	10	41.13	43.97	30	15.01.2006	2.3	4	41.22	43.83	51	13.05.2006	2.4	7	39.82	43.98
10	04.04.2005	2.4	10	39.68	43.82	31	15.01.2006	2.1	10	41.25	43.83	52	16.05.2006	2.5	7	40.4	45.03
11	06.04.2005	2.9	10	39.62	43.93	32	15.01.2006	2.5	10	41.27	43.85	53	22.10.2006	4.2	10	39.05	44.89
12	23.04.2005	3.3	7	39.67	44.2	33	18.01.2006	3.4	9	39.63	44	54	28.11.2006	4.6	5	39.94	42.65
13	23.04.2005	2.3	8	39.67	44.2	34	18.01.2006	2.9	5	39.62	43.92	55	14.12.2006	3.9	3	39.61	42.84
14	23.04.2005	2.7	10	39.67	44.3	35	19.01.2006	2.4	11	41.22	43.9	56	24.12.2006	3.1	8	39.33	43.63
15	23.04.2005	3.3	8	39.7	44.22	36	20.01.2006	2.2	8	40.3	44.02	57	26.12.2007	3.3	5	39.35	44
16	23.04.2005	3.4	8	39.68	44.2	37	25.01.2006	3.2	5	41.37	43.93	58	28.12.2006	3.4	12	41.01	43.7
17	23.04.2005	2.7	12	39.67	44.23	38	02.02.2006	2.6	14	41.23	43.88	59	21.01.2007	5.2	3	39.59	42.86
18	24.07.2005	2.2	10	39.7	44.3	39	09.02.2006	2.1	12	41.28	43.98	60	06.02.2007	3.2	5	39.59	42.79
19	29.07.2005	3	6	40.2	44.4	40	12.02.2006	2.8	9	41.3	43.82	61	09.02.2007	3.4	5	39.59	42.8
20	11.10.2005	2.5	16	41.07	43.97	41	17.03.2006	2	8	41.28	43.78	62	16.02.2007	4.6	5	40.51	42.36
21	18.10.2005	2.1	5	39.5	44.78	42	28.03.2006	2.9	5	41.32	43.97	63	26.03.2007	4.2	14	39	44.34

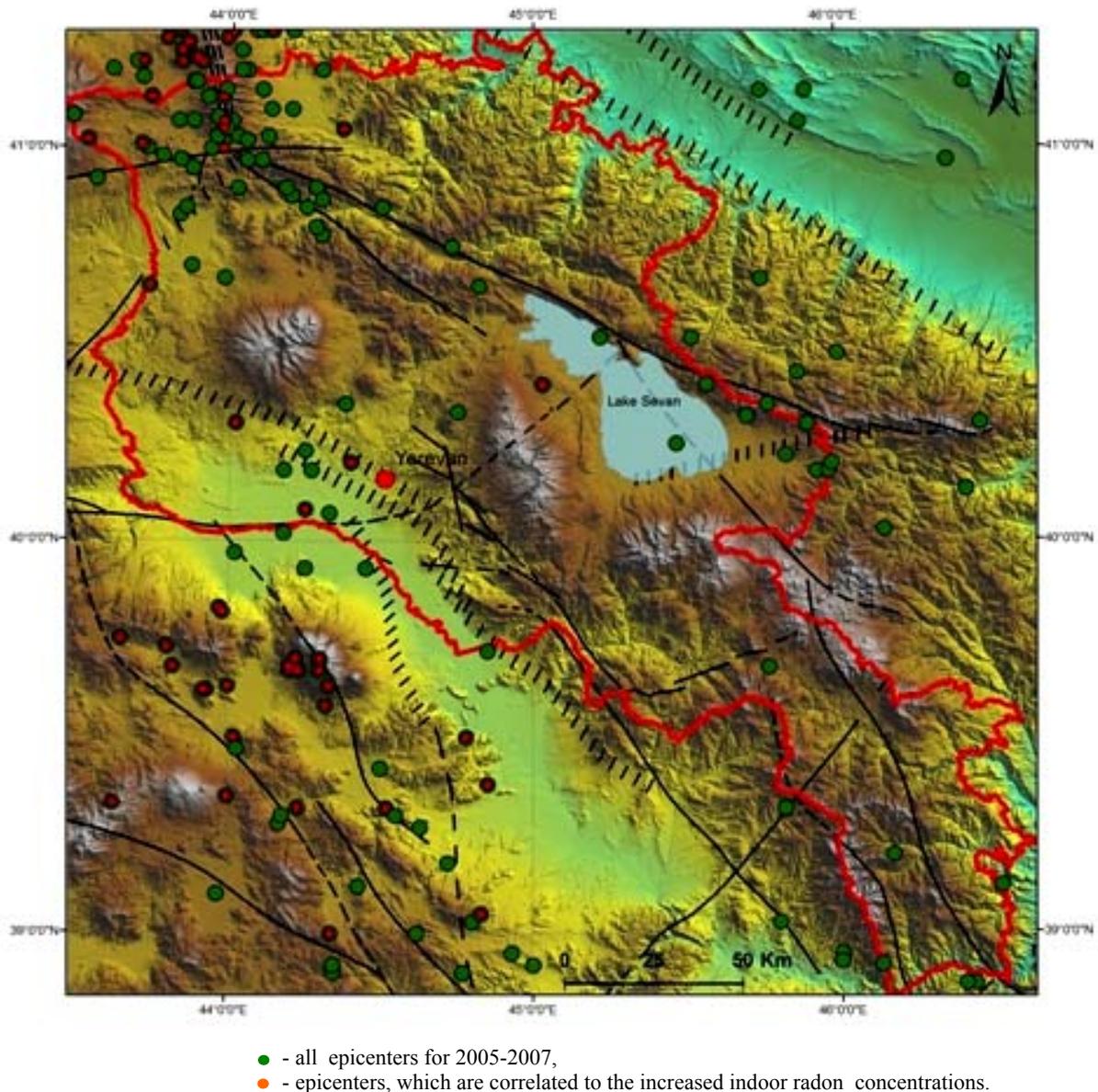


Fig. 10. The Spatial distribution of the earthquake epicenters (points) from 2005.01-2007.04

#### 4. Conclusions

As a result of the work performed, the following preliminary conclusions can be drawn:

1. In seismically active regions with unstable conditions of the earth crust, a major source of radon is not simply the soil itself, but also the soil as a component of the engineering and geological properties of the ground that has been built upon or is in the process of being built upon. The composition and the physical and mechanical properties of soils, the level of groundwater, the availability of small breaks and zones of micro-penetrability all play an important role. The combined effect of these factors determines the level of radon in dwellings.

2. Radon in the air of dwellings and other closed buildings does not just accumulate there, but also changes its concentration significantly on the eve of the earthquake. That is why the monitoring of indoor radon may be used as a component of a system for predicting seismic activity.

3. The significant increase in radon concentration in dwellings is characterized also by a prolonged period of high concentration after the earthquake before stabilization of the unstable seismically active condition of the area. This increases by many times the risk of cancer associated with alpha radiation (radon).

4. A contrasting increase in indoor radon concentrations in Yerevan (several times excessive vs. the sanitary norm) is predetermined not only by strong earthquakes ( $M \geq 4.5$ ), but also by weak ( $M < 4.5$ ),

small-depth (H-5-15km), regional ( $R \leq 200$  km from Yerevan) earthquakes and earthquake swarms which occurred in the territory of Armenia, as well as in Iran and Turkey.

5. Thus, in addition to all well known factors of radon danger, there is another factor – seismic factor specified not only with strong earthquakes but also with small ones and swarms.

The danger of the influence of natural radiation provoked by the earthquake exists for all urban territories of seismically active regions, and it requires coordination of investigations in different countries according to precisely-elaborated programs.

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